GE Energy Services

Cursory Generator Uprate/Upgrade Study

Intermountain Power Provider
Delta, UT

GE Energy Services
ICN Number G4578201

November 28, 2001

GENERATOR ENGINEERING PROPOSAL RESPONSE
LIQUID-COOLED GENERATOR UPRATE/UPGRADE STUDY

ICN Number G4578201	Sheet Number 2	Total # of Sheets 34
Customer Name Intermountain Power Project	Request for: **Generator Feasibility Uprate Study**	
Station Intermountain # 1	Frame Size: 112 – 54.3 x 280	Initiated By: Rayan Kassis/Jeremiah Smedra
Generator Number 280T150	Outage Date N/A	Generator Application Engineer Anh V. Nguyen
Turbine Number 270T150	Proposal Date 16/11/2001	Date Review by Gen. AE Manager 11/21/01

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Distribution:	1. \\Nyschs02psge\SDPE\Generator Service Engineering\GSE Req\cmugen\app\props 2. Generator Application Engineering Manager: Karl Tornroos 3. Commercial Manager or ICN Initiator:
Note:	This uprate is valid only when the work described above is completed and when the following conditions are met: • The generator contains only GE parts (since we cannot model non-OEM components) • Remaining components are in good working condition as verified by a thorough generator inspection by a GE Generator Specialist. (Electrical insulation is life limited.)

I. Executive Summary

Generator Application Engineering of General Electric Energy Services was requested to perform a cursory feasibility uprate study for generator S/N 280T150, presently Unit #1 at Intermountain Power Project in Delta, UT. The purpose of this study is to provide a cursory evaluation of the major generator components to identify limiting components requiring modification or replacement to support uprate potential. The generator, 280T150, is presently rated 991 MVA at 0.90 power factor (PF), and the potential uprate rating, as agreed by the customer, is 1056 MVA (950 MW) at 0.90 PF. This study includes the following major generator components: stator core and armature winding and rotor and field winding. The study also evaluates the capability of the Generrex CPS system to determine if it is capable of supporting the uprate potential.

Furthermore, the feasibility study identifies other generator components and auxiliary systems that would be possibly impacted by the uprate potential. A detailed design engineering study is required to assess these impacted components and auxiliaries to determine whether or not they can handle the uprate potential. At Intermountain Power Project's (IPP) request, the detailed analyses can be completed in a more extensive study.

II. Generator Uprate Performance Summary

GE records indicate that the generator is currently rated 991 MVA at 0.90 PF and 63-psig hydrogen pressure. This present rating corresponds to a maximum active power of approximately 892 MW and a maximum reactive power about 432 MVAR.

	Present Rating 991 MVA @ 0.90 PF and 63 psig	Proposed Option 1 1001 MVA @ 0.90 PF and 63 psig	Proposed Option 2 1056 MVA @ 0.90 PF and 75 psig
Electrical Design Number	DS554	TBD	TBD
KVA	991,000	1001,000	1055,556
KW	891,900	900,900	950,000
KVARS	431,967	436,326	460,106
Rated PF	0.9	0.9	0.9
KV	26	26	26
PSIG	63	63	63 or higher
RPM	3600	3600	3600
Field Amps	5363	5499	5748
H_2 Coolers (KW)	6849	7151	7591
Cold Gas Temperature, T_{CG}(°C)	46	46	46
Service Inlet Water Temp. (°F)	95	95	95

Table 1. Generator Ratings Summary

The requested uprate potential is 1056 MVA at 0.9 PF. This rating yields a maximum active power of 950 MW and a maximum reactive power of 460 MVAR. Table 1, Generator Rating Summary, summarizes the generator performance parameters of the original operating rating as compared to the uprate potential rating. It also includes the breakpoint rating (1101 MVA at 0.9 PF) at which the generator is limited.

The next section, Upgrades and Modifications of the Generator Components, discusses the performance capability of each major generator component in detail.

III. Upgrades and Modifications of Generator Components

The uprate assessment assumes the generator components are in an "As New" condition. Reliability issues associated with the age of components and additional duty on the components should be considered. Uprate can negatively impact the remaining life of older components.

Generator Component	Present Rating 991 MVA @ 0.90 PF and 63 psig	Proposed Option 1 1001 MVA @ 0.90 PF and 63 psig	Proposed Option 2 1056 MVA @ 0.90 PF and 75 psig	Comment
Stator Core	_____	No change required to support the power uprate	No change required to support the power uprate	. Not impacted by the power uprate
Stator Winding	_____	No change required to support the power uprate*	New stator windings required to support the power uprate	. *Stator Winding is limited at 1001 MVA
Generator Rotor	_____	Likely acceptable for the power uprate	Likely acceptable for the power uprate	. See section 3
Field Winding	_____	Need to increase the power factor to 0.93	Field insulation exceeding class B temperature	. Need to consider increasing power factor. See section 4
Excitation System (Generrex CPS)	_____	New excitation required to support the power uprate	New excitation required to support the power uprate	. Generrex CPS is limited at the existing rating. . Recommend EX2000

Table 2. Generator Components Requiring Modification or Replacement

1. Stator Core

If the stator core end iron is overfluxed, core damage can result due to incremental arcing between punchings and gross overheating of the end iron structure. The damage can range from bluing of insulation, to local arc damage, to catastrophic cascading core arcing resulting in armature ground wall failure requiring partial/full re-stacking and re-winding. The flux in the end region is heavily dependent on the armature winding currents and the power factor. Of course, The armature winding currents increase in direct proportion to the generator MVA rating. The flux entering the core ends increases as the power factor is increased from the rated value to unity in the lagging portion of the reactive capability curve and proceeds to increase further as the unit is operated at leading power factors.

For these reasons, the core end capability was considered as part of the power uprate evaluation. The study illustrates that the ends of the core are capable of supporting the uprate potential at 1056 MVA.

2. Stator Winding

The present stator winding itself could be capable of supporting an uprate up to 1001 MVA, at which point it exceeds mechanical and electrical design limits. Therefore, a new stator winding would be required to support the uprate potential 1056 MVA. However, it is not certain that even a new stator winding can be designed to meet the uprate potential since the generator 280T150 is one of GE's largest 2-pole generators, and its high operating rating may be well beyond GE experience. Hence, a detailed design engineering study is required to further verify if a new stator bar can be designed or optimized to meet the uprate potential.

3. Generator Rotor

A power uprate normally results in higher mechanical torsional stresses in the generator rotor, and these stresses may surpass the capability of the rotor. Thus, a mechanical evaluation of the generator rotor is imperative to determine its capability at the uprated condition.

A preliminary mechanical assessment of the generator rotor specifies that the steady state torsional stress is acceptable at the proposed rating 1056 MVA at 0.9 PF. Thus, the rotor is most likely capable of handling extra forces imposed on the rotor at the power uprate condition. However, a typical design intent of the rotor is 30 years, and the uprate puts an additional duty on the rotor that may negatively impact the remaining life of the rotor. Recently, several large steam turbine generators have experienced cracked generator teeth, which eventually caused arc strikes on the rotor teeth and dovetail load surface as well as on the mating surfaces of the slot wedges. Please refer to TIL-1292 for generator dovetail inspection recommendation.

4. Field Winding

The field current at the proposed rating 1056 MVA at 0.9 PF is approximately 7% higher than the present rated field current. The higher field current typically generates more heat in the field, so thermal capability of the field insulation may exceed class B limit temperature based on initial analysis.

Increased hydrogen pressure would mitigate the rise in field temperature, but would not compensate for the extra amount of heat generated in the field due to the increased field current. GE recommends that the field current should not be greater than the present rated field current, and this can be achieved by increasing the power factor at the same MVA accordingly. It is noted that as the power increases, significant added active power (MW) can be obtained, but this is done at some expense of reactive power (MVAR). For instance, the power factor can be increased to 0.96 at 1056 MVA to keep the field current not greater than the present rated field current. When the field current is constrained not greater than the present rated field current, the power uprate will have no impact on the field winding and other field-related components such as collector rings and brush rigging.

Similarly, the power factor can be increased to 0.93 at 1001 MVA to keep the field current constant and minimize the impact on the field winding and field-related components.

5. Excitation System (Generrex CPS)

The Generrex CPS is limited at the present rating. An increase in armature and field current could exceed the excitation capability. Therefore, a replacement of the excitation system is necessary to support the proposed uprates. Upon request, GE will provide technical background on EX2000 and outline the process of converting Generrex CPS to EX2000 excitation.

Summary

In summary, the 280T150 generator is at its original design limits, and there is a minimal margin for an uprate. The original stator winding is limiting, and the field current is much higher than the present rated field current. The higher field current typically generates more heat in the field, so thermal capability of the field insulation may exceed class B limit temperature based on initial analysis. However, the generator could potentially be uprated. At a minimum, a new stator winding will be needed to support the potential uprate rating 1056 MVA. Other generator components and auxiliary systems discussed in the next section, Detailed Design Engineering Study, need to be evaluated to determine whether or not they are capable of supporting the uprate potential.

IV. Detailed Design Engineering Study

The major generator components were reviewed in this study. However, the uprate of the generator usually impacts other components as well as auxiliary systems. Therefore, an extended power uprate study is needed to completely quantify the potential impact of the uprate. The following components would be typically evaluated in the detailed assessment phase study.

- Design and Optimize a New Stator Bar if Possible
- Stator Water-Cooling System
- Stator Water-Cooling System Coolers
- Current Transformers
- High Voltage Bushings
- Generator Rotor Torsional Mechanical Analysis
- Generator Coupling Mechanical Analysis
- Collector Components
- Brush Rigging Components
- Hydrogen Coolers
- Hydrogen Control System (If impacted by the uprate)
- Seal Oil System (If impacted by the uprate)
- Main Generator Ventilation (If impacted by the uprate)

V. Reliability Consideration

This uprate assessment assumes that components are in an "as new" condition. Reliability issues associated with the age of components and TIL's should be considered. In addition, IPP is encouraged to evaluate the condition of all other generator auxiliaries on the basis of age, overall condition, and additional demands placed upon them by the power uprate. To this effect, a copy of GEK-103566, Creating an Effective Maintenance Program, is attached.

Typical plant components that need to be reviewed in support of any generator uprate are the main transformer, isophase bus, Volts/Hertz protection, over and under-excitation circuitry, relay protections, switchyard breakers, and control room instrumentation.

Key Technical Information Letters are applicable to the generator:

TIL-1098 Inspection of Generators with Water-Cooled Stator Windings

TIL-1197 Liquid Cooled Stator Bar Abrasion

TIL-965 Copper Particle (Copper Dust) Contamination of Generator Fields

Other potential upgrades could include:

New H_2 seals are not required for the uprate but 180 degree, steel babbitted seals are recommended for reliability and reduced H_2 consumption.

Modifying the end shields can reduce the risk of oil ingress into the generator. Additional pumping ports, sealing grooves, and improved bolting are described in TIL-1098

VI. GEK 103566 – Maintenance, Testing, and Inspection (Rev 7/1994)

I. BACKGROUND

Implementing a thorough maintenance program is the most effective way to retain generator reliability and avoid major failure expenses. However, it must be cost-effective in that there are demonstrated savings in improved availability & reliability to offset the cost of implementing the program. The three important elements of a thorough program are maintenance frequency, electrical testing and visual inspection. It is the intent of this instruction to provide information on each of these elements, which will aid the owner/operator to establish a thorough and cost-effective maintenance program.

II. MAINTENANCE FREQUENCY

There are a number of components, which require routine maintenance or inspections between scheduled outages. The operator will find these recommendations in various equipment sections, and should also include additional maintenance tasks as operating experience indicates. Results of this routine maintenance should be retained in well-organized files readily available for reference. These routine maintenance records coupled with the information from the monitored operating data are a good indicator of pending service or operating problems that should be addressed at the next scheduled outage. The monitored information alone is usually not sufficient for tracking or highlighting trends.

During the first several months of operation, the stator winding support system and some of the other generator components experience a break-in period with more severe duty/wear than normal. Therefore, the first major maintenance inspection is recommended for one year after it is placed in service. If the unit's operating experience has been unusual because of misoperation or very limited in-service hours, etc. you may wish to discuss your particular circumstances with your local GE Field Service Office for recommendations specific to your circumstances.

Subsequent planned outages must also be performed in a timely fashion. Experience has shown that regularly scheduled maintenance outages are one of the most important steps in retaining unit reliability and reducing major repair/failure expenses. A minor maintenance outage is recommended every 30 months. During these outages the end shields or end plates are removed to permit inspection from the end winding area, but the field remains in place. A major outage is recommended every 60 months, and includes removing the field from the stator which permits a thorough inspection of the core section of the stator and field. The maintenance must include a comprehensive series of electrical tests and a thorough visual inspection. Each has their particular advantage and neither alone is sufficient.

Older generators with asphalt insulated stator windings and core lengths greater than 150 inches are subject to girth crack failures in the stator bars, and therefore, these generators should be reinspected twice as often (Minor Outage – 18 months; Major Outage – 36 months).

These recommended outage intervals have proven themselves over many years of use. However, high equipment reliability and outage costs, have lead to increasing interest in extending the time between major inspection. Condition Based Maintenance (CBM) is one method in development to do this, and is the focus of considerable attention in the industry. CBM relies on availability of reliable on-line instrumentation and evaluation techniques. As these evaluation methods become proven and practical, they will be incorporated into recommended operation and maintenance packages such that maintenance outages can be scheduled based on the condition of the unit.

III. TESTING

Generator electrical testing is focused on the insulation systems. However, there are other tests used to monitor for degradation in other components. A list of the typical tests recommended and the test purpose is shown in Table 1. Historical records of test results should be maintained and compared to the new test results. Changes between outage test results may point to needed repairs/rework that may not be evident from the absolute test values themselves.

Many of the tests require special equipment. Test results may be misleading and useless if the right equipment is not used, or it has not been properly maintained and calibrated to assure accurate results.

IV. INSPECTION

A visual inspection performed by an experienced individual can disclose unit conditions not detected by monitoring equipment or indicated by tests. Even the stator and field insulation systems must be significantly degraded to be detected by electrical testing. Also, for example, there is not a definitive test for contamination, rust, or oil and water leaks, and yet the presence of any of these could significantly adversely affect reliability and operation. A typical inspection should include those items listed in Table 2.

As important is it is, visual inspection is limited to areas that can be accessed for view either directly or with mirrors, boroscopes, cameras, etc. and therefore it must be combined with testing to give a complete picture of generator condition.

V. MAINTENANCE PLANNING

Major maintenance outages are usually scheduled well in advance of the actual outage date, and preparation for the outage should begin early. An important part of that is to review previous inspection reports for any indication of work needed, and review recommendations from GE communicated by Technical Information Letters, Engineering Change Notices, etc. to integrate those items into your plans. Materials you expect to need should be ordered to have available at the start of the outage to avoid the risk of costly delays waiting for material.

TABLE 1 – RECOMMENDED STANDARD TESTS

Test	Areas of Interest	Inspection Objectives & Assessment
(At Each Minor Outage)		
RTD Element Cu. Res.	Stator Gas & Winding	Check for calibration & poor connections
RTD Ground Insulation	Stator Winding	Insulation condition
Winding Copper Res.	Field & Stator Windings	Check for poor connection & breaks
Megohmmeter	Stator & Field Winding Bearing & Hydrogen Seal Ins	Insulation condition Integrity against shaft voltage
Over Potential / HiPot	Stator Winding	Ground wall insulation integrity
DC Leakage Current	Stator Winding	Contamination and/or deterioration
AC Impedance	Field Inter-Turn Insulation	Turn shorts & speed sensitive turn shorts
Vacuum Decay	Water Cooled Stator Winding	Water leaks in stator winding & hydraulic circuit.
Pressure Decay	Water Cooled Stator Winding	Water leaks in stator winding & hydraulic circuit.
(At Each Major Outage With Field Removed)		
Tracer Gas/Helium	Water Cooled Stator Winding	Detect Minute Leaks
Capacitance Mapping	Water Cooled Stator Winding	Wet ground wall bar damage
Magnetic Scalar Potential (El CID)	Stator Core Insulation	Weak or damaged core enamel
Wedge Tightness Map	Stator Wedges	Detect wedge tightness deterioration
(Optional / Diagnostic Tests)		
Partial Discharge Analysis	Stator Winding Insulation	Localized deterioration
Over Potential / HiPot	Field Ground Insulation	Ground wall insulation integrity
Water Flow Verification	Water Cooled Stator Winding	Restrictions in hydraulic circuit
Core Ring Test	Stator Core Insulation	Weak or damaged core enamel
Dynamic Freq. Response	Stator End Winding	Potentially damaging resonance
Air Gap Flux Probe	Field Inter-Turn Insulation	Turn shorts at operating speed

Your maintenance program should reflect the level of acceptable risk for the unit. That will probably vary from unit to unit and plant to plant, and will change over time as the importance of the unit to the power system changes. In addition, new technologies are constantly being developed to improve unit reliability, performance, monitoring, & inspection equipment, and otherwise provide more cost-effective means for maintaining the generator. The owner/operator should be aware of these developments and modify the maintenance program accordingly. While this should be a continuous process, the "maintenance outage planning review" is an appropriate checkpoint.

Your local GE Field Service Office can assist you in your maintenance planning, and review of your overall maintenance program, incorporating any appropriate new maintenance and upgrade technologies available.

TABLE 2 – VISUAL INSPECTION AREAS

		Foreign Material/Contamination	Cleanliness	Loose or Displaced Parts	Movement	Mechanical Damage	Deterioration (General)	Corrosion	Surface Condition and Wear	Water Leaks (Water-Cooled Winding)	Cracks	Worn Parts	Burning	Blocked Ventilation	Bar Sparking	Tape Migration	Broken Tiles	Shorted Core Punchings	Core Tightness
Stator	All Components	X	X	X	X	X	X												
	Bars									X	X	X	X		X	X			
	EW Support System										X	X		X					
	Slot Support System											X		X	X				
	Conn. Rgs & Lower Lds.									X	X	X	X				X		
	High Voltage Bushings									X	X		X	X					
Core	All Components	X	X	X	X	X	X	X										X	X
	Core End										X		X	X					
	Ventilation Ducts													X					
	Laminations												X					X	X
	Key Bars																		X
Field	All Components	X	X	X	X	X	X	X	X										
	Body & Wedges										X		X	X	X				
	Retaining Rings										X		X						
	Fans										X								
	Spindles										X	X							
	Winding													X	X				
	Collectors											X	X						

Note: All generator components have been modeled in "As-New Condition". Some degradation is certain to have already occurred. In addition, operation at higher ratings will accelerate future degradation, reducing future component life expectancies. Of special importance is the additional stress placed upon the stator windings and its effect on present and future stator coolant leaks. For typical generator winding life expectancies.

VI. Technical Information Letters (TIL)

TIL-1098: INSPECTION OF GENERATORS WITH WATER COOLED STATOR WINDINGS

APPLICABLE TO

Generators with water-cooled stator windings

PURPOSE

Update GE recommendations regarding testing, repairs, maintenance, and long-term operation of generators with water-cooled stator windings. NOTE: This revision supersedes TIL 1098-3R1 issued September 16, 1993. It contains important new information on the root cause of clip-to-strand braze joint leaks based on recent development work, and provides updates on test and inspection experience related to water leaks and oil contamination.

BACKGROUND / DISCUSSION

GE generators with water-cooled stator windings have amassed an outstanding reliability record since their introduction in 1960. Over 450 machines have been placed in operation, with the bulk of the units entering service in the 1970's. The average service age of the fleet is over 20 years, the oldest being about 34 years.

A 1990 review of historical data, as well as test and inspection results compiled from operating water-cooled generators, identified stator winding leaks and oil contamination as two important issues affecting the service life and reliability of this equipment. Since then extensive investigations and analysis have been conducted to understand the root cause and solutions for stator winding water leaks.

STATOR WINDING LEAKS

Stator winding cooling system water leaks have occurred randomly since the introduction of water-cooling. However, there has been only one in-service failure due to water leaks over the last 30 years. The failure occurred as a result of water leaking from a phase joint to the adjacent phase, which precipitated a flashover. All other leaks have been found during maintenance outages.

In the late 1980's GE began to see significant changes in the effects of water leaks. For 20 years prior to 1988 only one water-cooled bar failed maintenance electrical testing. But from 1988 through 1990 there were seven failures. Investigation of the failed bars indicated the presence of water in the groundwall insulation was a significant factor in their failure. Subsequent inspection of bars with wet end-arm insulation revealed the
water source to be leaks originating at the clip-to-strand braze. Even when wet insulation is not detected, clip-to-strand leaks are the most serious because they can only be repaired on a best-effort basis, and require bar replacement for greater long-term reliability.

As a result of these experiences, it is evident that more attention is required to eliminate water leaks affecting the stator bar groundwall insulation, particularly on the stator bar end arms. Even extremely small water leaks can be detrimental if allowed to persist. This is particularly the case if the stator water pumping unit is left in operation during maintenance outages when the generator is degassed. Under these circumstances the pressure differential provides the greatest impetus for water to be forced through a leak site into the groundwall insulation. Regardless, capillary action can cause water to leak from a bar even though hydrogen pressure is maintained higher than the cooling water pressure.

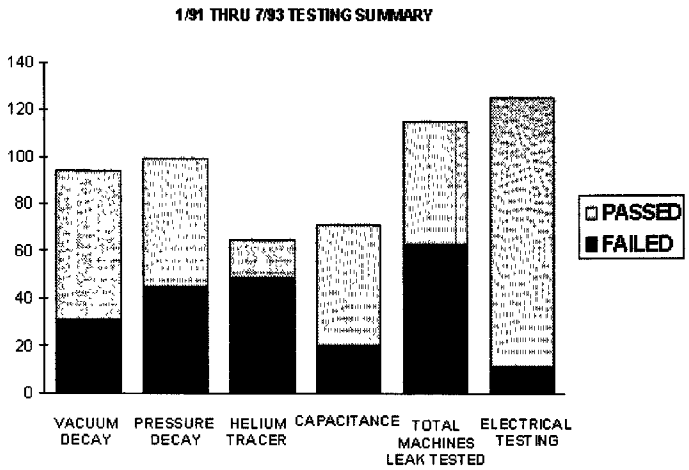
If water leaks occur, they generally develop in the region of the series or phase connections. Stator bars are stringently tested for leaks prior to assembly, and the entire winding is tested twice after assembly to further ensure winding integrity. Leaks which occur in service develop under normal operating conditions and often take a long time to occur.

Clip-To-Strand Braze Joint Leaks

Since 1990 GE has had an ongoing development program to investigate the water leak phenomenon. Recently completed corrosion simulation tests and an analysis of clips from leaking bars indicate crevice corrosion is a significant contributor to development of clip-to-strand braze joint leaks.

Leak Analysis a number of leaking clips have been analyzed from different generators. The leak paths in each of the clips analyzed were similar. In each case, the cross sectional size of the leak path stayed relatively constant over its entire length. This indicates the depth of the penetration into the copper and adjacent braze was indeed limited. However, the corrosion mechanism was able to continue by driving down the length of the copper strand. This coupled with the selective attack of the phosphorous-rich phase indicates the corrosion reaction needs phosphorous to "fuel" the process.

1/91 THRU 7/93 TESTING SUMMARY



The evidence discovered here revealed a leak process that initiates in the braze alloy at the inner surface (a crevice corrosion mechanism), and under the right conditions changes to corrosive penetration of adjacent copper (phosphoric acid attack), with a limited depth and cross section.

Corrosion GE's analysis of the crevice corrosion phenomenon in clip-to-strand braze joints shows it to be a two stage process.

The first stage of the corrosion process (Phase I) consists of corrosion of the braze alloy inside the clip at the strand ends. Water works its way into existing small voids at the braze surface (due to the "spongy" nature of the braze) and stagnates. If conditions are right (i.e. void size), crevice corrosion of the braze takes place attacking the phosphorus rich phase of the braze alloy. Initial void sizes increase as material corrodes. The water chemistry changes to phosphoric acid as a result of crevice corrosion of the braze alloy. The Phase I process is limited by the crevice reaching critical volume, solution chemistry and precipitating out phosphate salt along the surface of the braze which slows/stops further corrosion.

The second stage (Phase II) of corrosion begins if the copper strand is contacted by the void as it grows. This causes a corrosive attack of the copper strands by the phosphoric acid solution created by corrosion of the braze alloy. The corrosion of the copper strands takes place preferential to the braze alloy and at a higher rate. The depth into the copper is limited and roughly constant (approximately 0.015 inches), partly by the precipitation of phosphate salt on the copper, and partly by the volume of the liquid becoming too large to maintain the critical acid concentration. The corrosion mechanism changes (due to a change in water chemistry) and the phosphorus-rich phase of braze is again attacked. Then, as the solution chemistry changes due to phosphorus being added to the solution, preferential attack of the copper occurs. The mechanism switches back and forth from crevice corrosion of the braze alloy to acid attack of the copper as the leak path makes its way down the strand.

Stator Cooling Water System

Oxygen Content Design of the stator cooling water system requires that the deionized water remain highly aerated with the oxygen content of the water in the range of 2 to 8 ppm. This level of oxygen is conducive to the formation of a tough, tenacious and stable cupric oxide film on the inside surfaces of the stator winding. The film protects the copper from erosion and excessive corrosion. In cases where the oxygen level of the deionized water falls below about 0.5 ppm, the production of cuprous oxide increases markedly. This oxide layer is much less tenacious than the normal cupric oxide, and as such, has a tendency to slough off the copper strands and enter the water stream.

There are four possible problems associated with this phenomenon:

1. Repeated oxide formation and sloughing results in a consumption of base metal, thereby increasing the likelihood of stator winding leaks.

2. Oxides in the water stream can cause field grounds by bridging water-cooled rectifier Teflon tubes.

3. Excessive cuprous oxide formation can restrict proper cooling water flow to stator bars.

4. Copper oxide particles will collect in the resin bed and stator water-cooling system filters and decrease their effectiveness and life expectancy.

Deonizer Resin It is important that the stator cooling water and deionizer resin be maintained to proper GE standards to assure optimum operating performance. Recent field experience shows use of resins not adhering to GE specifications leads to problems with the stator cooling water system (see items 2 through 4 above).

YTV Vent Pipe The deionized water remains aerated by virtue of the atmospheric vent (YTV) originating at the water storage tank. Two conditions can hinder the aeration:

1. Restriction in the YTV Vent: If the vent becomes restricted, and the tank no longer freely communicates with the atmosphere, a hydrogen blanket will form in the top of the tank. Over the course of time this causes the oxygen content of the water to decrease. Some generators were originally designed with a special valve arrangement on the YTV vent (see Figure 2 on Page 7). Experience shows this arrangement does not allow the tank to breath properly. Modifications should be made to the YTV vent piping scheme to ensure a free exchange of hydrogen into the atmosphere and air into the tank (see Figure 3).

2. Large Water Leak: Experience shows that when a leak occurs in the stator winding circuit, water leaks out and hydrogen makes its way through the leak into the stator cooling water system. If the leak is large enough a blanket of hydrogen forms in the top of the stator water cooling system tank, effectively isolating the tank from atmosphere by restricting the free flow of air down the vent. Isolation appears to begin at about 20 ft3/day hydrogen leakage, however, its exact level depends on the geometry of the vent and various operating conditions at each specific site. Isolation can occur even on a YTV vent that communicates freely.

The recently developed Stator Leak Monitoring System (SLMS) prevents isolation from occurring in the water tank. The SLMS system is used to both oxygenate stator-cooling water in a more positive manner as well as measure and trend the level of hydrogen escaping out of the YTV vent.

Leak Testing Methods

GE recommends four basic tests in addition to a weekly check of the stator water-cooling system (YTV) vent and liquid level detector:

Vacuum Decay
Pressure Decay
Capacitance Mapping
Helium Tracer Gas

Early detection and timely repair are key to minimizing damage resulting from water leaks within the generator.

Publication GER-3751 "Diagnosing And Repairing Water Leaks in Stator Windings" contains detailed information on leak testing. Your local GE PGSD or IPGS representative can provide a copy of this publication, supply additional information, and provide qualified technicians and specially designed equipment to perform recommended tests and inspections.

In addition, publication GEK-103566 "Creating An Effective Maintenance Program" contains a complete listing of all standard tests recommended for generator maintenance. This publication was issued with TIL 1154-3 "Generator Test and Inspection" dated June 30, 1994.

Leak Testing Experience

With the issuance of the original TIL 1098-3 in May 1991, GE recommended a series of tests to evaluate hydraulic integrity of the stator winding. The results of these tests have been tracked since 1991.

Table 1 on page 6 shows test results from generators with bars having failed electrical testing. Of those generators that had bar failures; 7 of 9 passed a vacuum decay test and 5 of 10 passed a pressure decay test. Yet, all tested failed both helium tracer gas and capacitance mapping tests. ***These test results show that passing both the vacuum and pressure decay tests does not guarantee a leak free winding***. The results also demonstrate the importance of the helium tracer gas and capacitance mapping tests.

Bar Failures Since January 1991 there have been 15 instances of water-cooled stator bars failing either the HIPOT, DC leakage, or megger electrical tests resulting in bar replacements. In 14 of the cases wet insulation was the cause of the failure. The other failure was due to slot and endwinding support system looseness caused by oil. The water source for the wet insulation was a leak in the stator bar clip-to-strand braze joint region.

Bar Repairs Window, porosity, and piping leaks were permanently repaired by rebrazing or TIG welding. Some did require component replacement(s), including: elbows, tees, piping, hoses, and fittings.

Clip-to-strand braze joint leaks, the most difficult to detect and repair, allow water to migrate along the bar end arm and into the groundwall insulation. Once penetrated by water (as determined by the capacitance mapping test), the groundwall insulation is irreparably damaged and the bar should be replaced. These leaks cannot be field rebrazed because the high temperature will damage nearby insulation. The leaks were repaired using anaerobic cement, applied on a "best effort" basis, for temporary return to service. This allows the user to postpone more extensive/permanent repairs to a later date. There is no way to quantify the effectiveness of this repair. However, many of these repaired bars are still in service today.

Testing Results From 1989 to 1993, 47 generators experienced leaks in the clip-to-strand braze joint region, 18 of these required bar replacement(s) due to failing electrical testing. An additional seven units also failed the capacitance mapping test. Users elected to replace bar(s) in those seven units because the groundwall insulation was irreparably damaged. Also, these users had spare bars on hand and wanted the greatest assurance of a permanent, reliable fix. Leaking bars in the remaining 22 units were repaired on a "best effort" basis and the units were put back in-service. Some of these repaired bars have since been replaced for greater long-term reliability.

Figure 1 on page 6 summarizes results of testing reported to GE. This data represents an estimated 85% of the tests done from January 1991 through December 1993 (results from early 1994 are not available as of this writing). Figure 1 confirms the success of the recommended tests in detecting leaks and highlights the importance of routine maintenance leak testing.

Helium Tracer Gas Helium tracer gas testing has found leaks in 59 of 78 generators, confirming the high sensitivity of this test. In 90% of the cases, the leak detected by the helium tracer gas passing through the insulation (either series loop or groundwall) was confirmed by a snoop test after the insulation was removed. The other 10% generally showed traces of helium in various locations, not concentrated enough to pinpoint for repair.

Capacitance Mapping The capacitance mapping test has uncovered "wet" insulation in 26 of 86 generators tested. Eleven of the units that failed the capacitance mapping test also failed electrical testing, strongly attesting to its validity. Seven users elected to replace bars, before electrical testing, on the strength of the capacitance mapping test alone. Two units passed a suitability for service HIPOT and one passed a reduced voltage HIPOT. One user did nothing, but is planning a rewind. No information is available on the other four units.

Total Leak Tested The total machines leak tested column in Figure 1 indicates that 80 of 141 failed one or more of the four recommended leak tests.

Electrical Testing In the 6 outage seasons that Figure 1 spans (1991 through 1993), there have been 13 instances of water cooled stator bars failing electrical tests resulting in bar replacements. These failures were 6 HIPOT, 6 DC Leakage, and 1 Megger. The total number of units electrically tested is an estimate based upon the assumption that only about 50% of the units are electrically tested every 5 years.

OIL CONTAMINATION

GE generators are tolerant to small amounts of oil contamination. Too much oil can be defined as any measurable quantity on a regular basis, whether it be a gallon per month or cup per day. There have been a number of cases, however, where large quantities of oil have been allowed to enter the generator over an extended period. If the bar slot support system becomes saturated with oil, the friction component of the side ripple springs is reduced and its effectiveness is diminished.

The bar restraining systems in the slot and endwinding incorporate the following features that help to accommodate the increased bar forces in a water cooled generator:

A zero radial clearance design and side friction in the slot.
A GE patented endwinding support system (TETRALOC) .

It is important that slot and endwinding support systems be well maintained in accordance with standard GE recommendations. Deterioration of any part in the bar restraining system may lead to damage of stator cooling water circuits and accelerated wear of stator winding insulation. In November 1993 a stator bar failed a HIPOT test due to oil contamination affecting the bar restraining system.

There are two main sources of oil contamination:

1. Leakage along the joints between the endshield halves and hydrogen seal casings:

Although the assembly is relatively straightforward, several circumstances can cause an unsatisfactory seal. Some generators may benefit from a change to a more effective sealant, replacing the Titeseal normally used.

2. Backup of oil from the hydrogen seal drain:

This may be the result of either a failure of the float trap or extended operation of the seal system with little or no gas pressure in the generator. In either case, a high level alarm in the seal drain enlargement will precede oil entry into the generator. If this occurs, corrective action should be taken immediately, such as bypassing the float trap and/or increasing gas pressure, or degassing and shut down of the seal oil system.

MAJOR OUTAGE MAINTENANCE TESTING PLAN

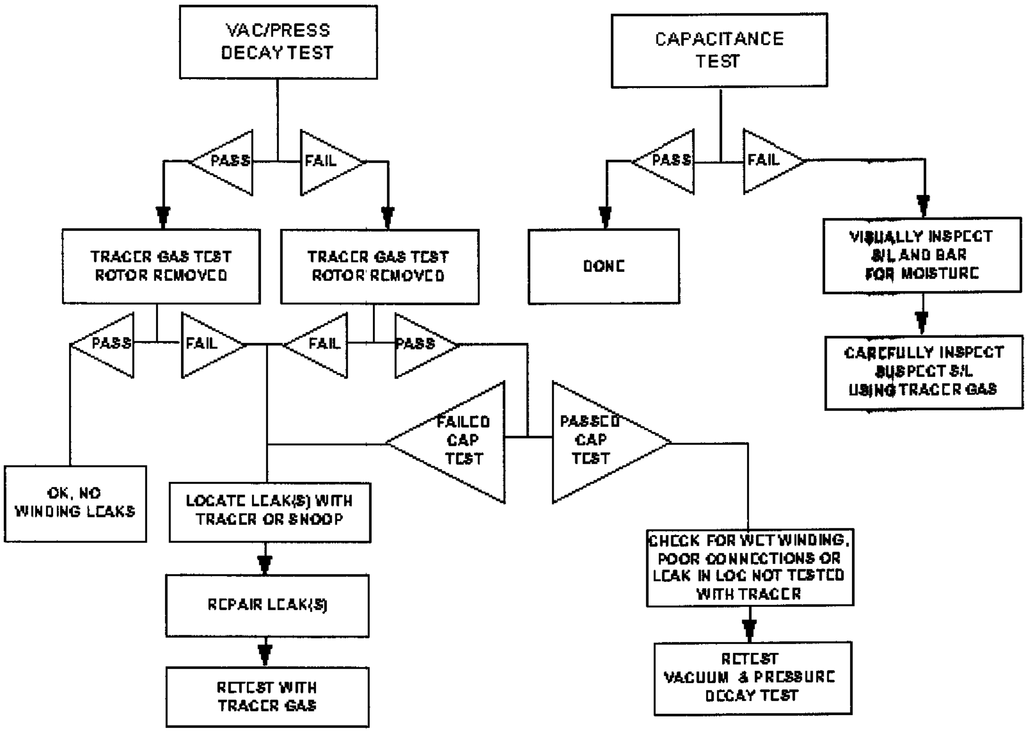


Figure 1

UNIT	VACUUM DECAY (ACCEPTANCE LIMIT 3.0)	PRESSURE DECAY (ACCEPTANCE LIMIT 1.0)	HELIUM TRACER GAS	CAPACITANCE MAPPING
A	N/A	6.3 (FAIL)	FAIL	FAIL
B	PASS	PASS	FAIL	FAIL
C	0.7 (PASS)	0.9 (PASS)	FAIL	FAIL
D	1.8 (PASS)	0.9 (PASS)	FAIL	FAIL
E	FAIL	FAIL	FAIL	FAIL
F	1.2 (PASS)	1.7 (FAIL)	FAIL	FAIL
G	FAIL	FAIL	FAIL	FAIL
H	N/A	N/A	FAIL*	FAIL*
I	N/A	N/A	FAIL	N/A
J	PASS	PASS	N/A	FAIL
K	N/A	N/A	FAIL	FAIL
L	N/A	N/A	FAIL	FAIL
M	PASS	FAIL	FAIL	FAIL
N	O.85 (PASS)	0.18 (PASS)	FAIL	FAIL
TESTED AFTER BAR WAS REMOBED				

Table 1. TEST RESULTS FROM UNITS WITH FAILED BARS FOR 1/91 TO 8/94

RECOMMENDATIONS (*Indicates new or revised)

1. Remove the water system from operation when the generator is off-line and degassed. This will help prevent insulation damage during downtime.

2. *Maintain the stator cooling water and deionizer resin to proper GE standards to assure optimum operating performance. Use only resin supplied by GE (Dwg No. 233A8688P0001) or GE approved sources. The resin has a useful life of 24 months and should be changed at every maintenance outage. Its shelf life is approximately 4 months. Also, for outages longer than 2 days, follow one of these three recommendations:

- Maintain stator cooling water flow with gas pressure higher than water pressure
- Connect YCF to YCD with temporary flush pipe to remove stator winding from system. Water flow may now be maintained without need for gas pressure
- Shut down stator cooling water system and replace the resin bed at the end of the outage.

3. *Consider installing SLMS (Stator Leak Monitoring System) on the generator at the next available opportunity to better monitor and trend the hydrogen leakage out the YTV vent and provide a more positive means of oxygenating the stator cooling water.

4.* Monitor the oxygen content of the stator cooling water on a monthly basis by having a sample analyzed. Appropriate remedial action is recommended if oxygen content falls below 0.5 ppm.

5. *The following tests are recommended:

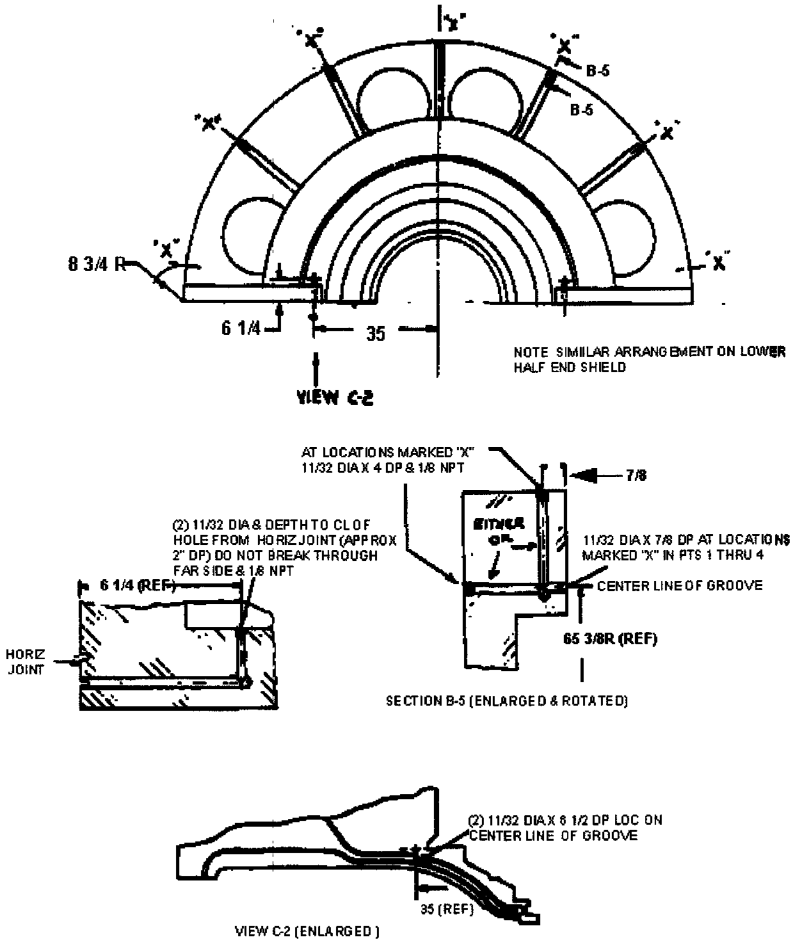
Weekly

- o Check the liquid level detector in the bottom of the generator.

- o Check the stator water-cooling system (YTV) vent for an upward trend or step increases in hydrogen flow out the vent. Experience shows that YTV vents configured with a triple path valve arrangement (see figure 2) do not allow the tank to breath properly. One pipe leads to a normally closed valve (Y-77), the second pipe leads to a pressure relief valve (Y-78) set at 14" WC, and the third pipe leads to a vacuum breaker valve (Y-79) set at 1" HG VAC. If your YTV piping arrangement is as shown in Figure 2, modify the piping as shown in Figure 3. This modification eliminates restrictions in the piping between the SWCS tank and the YTV vent line to ensure a free exchange of hydrogen into the atmosphere and air into the tank.

The following steps can be taken to accomplish the modification.

1. To prevent contamination of the SWCS, insert the reversible spacer blank into the flanged connection between the SWCS tank and the YTV vent line.
2. Cut the triple path valve arrangement out of the vent line.
3. Connect the remaining open ends to each other using schedule 80 carbon steel pipe with socket weld type fittings as needed.
4. A trap with a rise of at least 6" may be added at the Y-80 valve in lieu of draining the valve once a day.



Minor/Major Outages

- At each minor outage (30 months) perform vacuum and pressure decay tests of the winding circuit. Failure of either test indicates a leak in the winding. A helium tracer gas test is then recommended to locate the source of the leak for repair. A capacitance mapping test is also recommended to determine the extent of water penetration of the groundwall insulation. Repairs should be made prior to restarting the generator.
- At each major outage (60 months), in addition to the vacuum and pressure decay tests, perform a capacitance mapping test on the end arms of each bar on both ends of the unit and a helium tracer gas test on the series loops on both ends of the generator. As an option, with at least all the upper half endshields removed, the helium tracer gas test can be performed during a minor outage.

5. *Recent analysis indicates crevice corrosion is a significant contributor to development of clip-to-strand braze joint leaks and, because of the crevice corrosion mechanism, these leaks will continue to propagate. The best assurance to eliminate these leaks and for greatest long-term reliability would be a full stator rewind.

6. GE experience shows outage time from failed bar(s) replacement and water leaks is reduced if spare stator bars, long shelf life installation material, and short shelf life series loop/phase connection insulation material is readily available. GE recommends stocking these materials to reduce outage time.

NOTE

Due to shelf life limitations, order short shelf life series loop/phase connection insulation material (tape, resin, putty, varnish, etc.) no earlier than two months prior to an outage. GE experience shows that short shelf life material for at least 10 connections should be on hand, this is especially important for international locations.

	4 Pole No. Slots				2 Pole No. Slots				
	54	60	66	72	36	42	48	54	60
	Recommended No. of Bars								
Top Bar	14	15	17	18	18	21	23	25	27
Bottom Bar	4	4	4	4	4	4	4	4	4
P Bar	1	1	1	1	2	2	2	2	2
For Machines with Gennerex Excitation system									

Spare stator bars and long shelf life installation material can be stored indefinitely. Refer to the above table for recommended stocking quantities of stator bars.

7. Use care during assembly and inspection of generator end shields, hydrogen seal assemblies, and oil deflectors, to avoid creating sources of oil leakage/contamination.

8. If problems have been experienced with sealing end shields, an improved sealant, GE drawing number 164A7383P0009, is recommended. This sealant is impervious to oil, has constant viscosity with temperature, and remains pliable with age. Sealant gun assembly 213B6544G0001 is also required for proper application of the sealant.

Figure 4 is a typical endshield showing a typical pumping port arrangement for the channel sealant. GE experience shows sealant does not flow correctly if the channel (pumping groove) between pumping ports exceeds 40 inches in length. The sealing groove may require additional pumping ports to reduce the channel length between ports. Maintain pumping port sizes and grooves as shown in Figure 4.

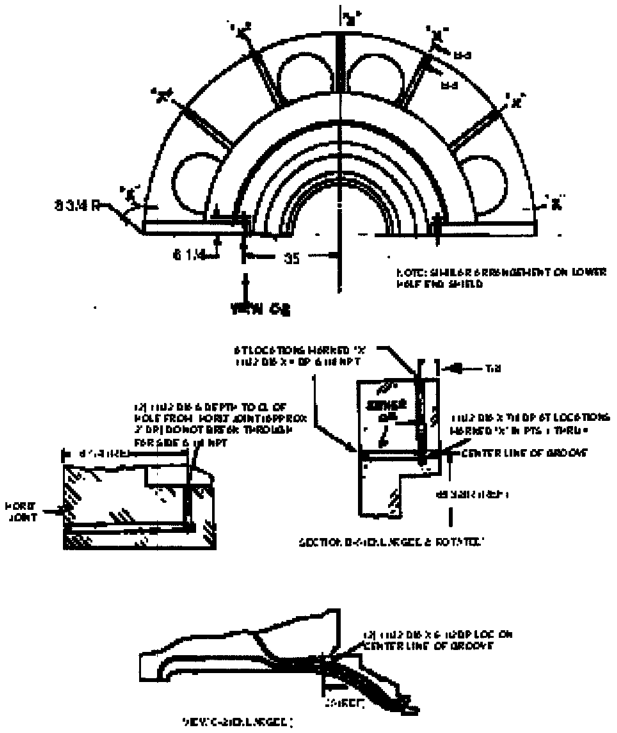


Figure 4

TIL-1197: LIQUID COOLED STATOR BAR ABRASION

January 31, 1997

APPLICABLE TO

Generators with liquid cooled stator windings

PURPOSE

Provide inspection, testing, and maintenance recommendations to address liquid cooled stator bar abrasion on the slot portion of the winding.

BACKGROUND / DISCUSSION

Liquid cooled stator bar abrasion is the result of a combination of factors: development of radial clearance in the stator core slot, oil contamination of the stator winding, and stator bar electromagnetic forces. These factors can be present on any liquid cooled stator winding regardless of its manufacture. Historically, all OEM's have experienced this problem to some degree. Stator bar abrasion is a potential degradation mechanism that can be prevented with regular generator tests and inspections, proactive preparations to take action, and timely maintenance based on GE recommendations and solutions.

Some liquid cooled generators have developed stator bar abrasion at the ends of the core slot. In some cases the abrasion has led to major damage of the ground wall insulation resulting in electrical failure and, consequently, a partial or full stator rewind.

Historical Experience

Prior to 1995 there were only a few isolated reports of liquid cooled stator bars that had exhibited significant abrasion. In those instances there was also evidence of extensive oil ingestion and oil saturation of components within the generator casing. For liquid cooled generators, which have higher bar forces and currents compared to conventionally cooled units, it has been known for some time that long term exposure of stator components to excessive amounts of oil can lead to accelerated wear and maintenance issues. This potential for excessive wear in liquid cooled generators has been described in TIL 1098-3R2.

Recent Experience

During 1995, there were four major findings of bar insulation abrasion requiring bar replacement. Two cases resulted in forced outages and two occurred during tests and inspections during maintenance outages. The service ages of these machines, both 2- and 4-pole, ranged from 12 to 23 years. The winding deterioration in each case was due to stator bar insulation abrasion and wears caused by bar vibration while the generator was operating. In all cases, oil was present inside the generator and varying amounts of "greasing" were found on the stator core and stator wedges. It was determined that the four affected stators had developed significant radial clearance in some of the stator slots and that this clearance allowed the bars to move and vibrate radially in the slots.

There are over 500 generators with liquid cooled stator windings. The average age of this fleet of generators is about 22 years. During 1995, over 25 of these generators were inspected for evidence of bar wear. This included testing to determine radial clearance in the slots, inspecting for evidence of oil and greasing in the stator, and checking stator wedge tightness. The results of these inspections revealed that some of these generators were experiencing various degrees of bar wear/abrasion and indicated that others had the potential for developing bar abrasion. A majority of these units exhibited no evidence of bar abrasion.

Inspection Results

The stator bars that experienced wear and abrasion during service due to the radial vibration, had developed radial clearance at the ends of the stator core. Also, there were varying amounts of oil and greasing present at the degraded areas. The nature of the damage was abrasion and wear on the bar armor, ground wall insulation, and stator core caused by the stator bar vibrating in the radial direction. In all cases the affected areas were confined to the surfaces of the stator bars and core within the first five feet of the ends of the core. No evidence of vibration or wear was observed on the balance of the stator winding and core. The depth of the wear into the ground wall insulation in some cases exceeded 50% of the insulation thickness. This degradation of the ground wall insulation resulted in the bar failures mentioned previously. Of the windings experiencing abrasion wear or failure, there has been no circumferential pattern nor any higher incidence of failure of one end of the generator (TE or CE) versus the other.

The results of recent inspections have confirmed the importance of a regular generator test and inspection program. Furthermore, the importance of maintaining a radially tight stator winding in the core has also been demonstrated. In cases where early evidence of winding looseness and oil contamination was observed during a prior outage, and stator winding maintenance was either not recommended or postponed, stator bar abrasion damage had progressed significantly and, in some cases, to a severe degree.

Wedges are normally tested during maintenance outages and those generators with tight wedges were thought to indicate no slot clearance was present, and thus, no potential bar radial movement and subsequent wear would occur. However, the recent inspections have shown that end wedges can be tight even when there is clearance within the slot.

Inspections and analysis to date indicates bar vibration and abrasion has not occurred without the presence of oil contamination in the stator. In all cases, where a failure has occurred or wear was evident, there was evidence of oil or greasing in the generator. The greasing was always observed in the outer five feet at the ends of the stator core. While oil by itself could not cause the bar vibration without radial clearance, it is a significant contributing factor in accelerating and propagating the stator bar wear. All steps should be taken to prevent oil ingestion into the generator and to remove oil that does make its way into the generator.

Stator Bar Abrasion Mechanism

GE's liquid-cooled generator stators employ a "zero radial clearance" slot support system on the winding (see Fig. 1 Liquid Cooled Stator Slot Cross Section). This is achieved by using conforming materials within the slot support system that are cured under conditions of\ pressure and elevated temperature by means of a radial pressure-molding process. The conforming materials and molding process accommodate surface irregularities on the stator bars and compact the slot contents towards the bottom of the slot, thereby eliminating all radial clearance. Side ripple springs are employed to assure stator bar surfaces are sufficiently grounded and to damp stator bar vibration by increasing frictional forces between the bar and the slot wall. A tapered wedging system provides high radial forces that are intended to assure zero radial clearance initially and for long periods of operation.

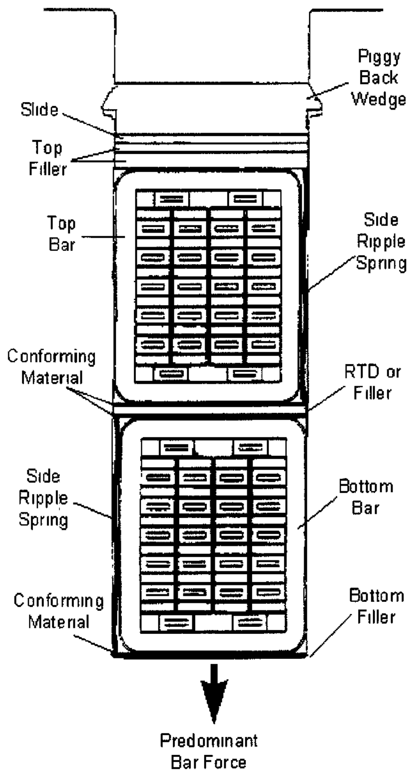


Figure 1. Liquid Cooled Stator Slot Cross Section

Customer:	Intermountain Power Project	**Generator DL**	280T150
ICN No.	G4578201	**Turbine No.**	270T150
Generator No.	280T150	**Frame Size**	112 – 54.3 x 280
	Sheet # 30 of 34		Proposal Date: 8/11/2001

Based on GE's investigation, a contributing factor to the stator bar abrasion is radial clearance that can develop in the stator slot over the life of the machine. Particularly critical are clearances occurring at the ends of the stator core between the top and bottom bars and between the bottom bar and the slot bottom. Once clearance develops in the slots, the bars become more vulnerable to radial vibration while the generator is inservice. The development of radial clearance in a stator slot can be a result of the gradual shrinkage and compression of slot contents, such as stator bar armor, slot fillers, and wedges, that can occur on a stator winding during normal, long-term operation. However, radial clearance alone does not necessarily lead to stator bar abrasion.

To accommodate higher machine ratings, generators have increased in physical size and hydrogen pressure. These factors can make it more difficult to achieve and maintain an oil-tight hydrogen seal casing and outer endshield assembly. In some instances, the assembly has resulted in leak paths for hydrogen seal oil to flow across bolted joints, particularly the horizontal joint of the endshields in the vicinity of the hydrogen seal casing. The oil can be entrained in the circulating hydrogen cooling gas and distributed throughout the generator. Other causes of oil ingress can be misoperation of the hydrogen seal oil system and failure of the hydrogen seals and oil deflectors. Depending on the amount and the duration of the oil ingress, contamination of the stator winding and slot support system can result.

Oil contamination of the slot contents diminishes the effectiveness of the slot support system and can accelerate stator bar abrasion by reducing the restraining friction forces between the bar, side ripple spring and core, and allowing bars with clearance to vibrate during operation. If zero radial clearance is not maintained and significant oil contamination of the winding is present, then radial stator bar vibration may occur, due to normal operating electromagnetic forces, which can result in stator bar insulation abrasion. "Greasing", which is a mixture of the oil and wear products from the stator bar insulation, slot support system, and core iron, may develop. Greasing can be visually detected between the wedges and core, at the ends of the slot, and in the core vent ducts.

During operation of any turbine-generator, the armature current induces a twice per cycle force on the stator bars, predominately towards the bottom of the stator slot. The liquid cooled stator winding, which GE has designed to operate with zero radial clearance in the stator core slots, should not move radially relative to the stator core slots. However, if radial clearance develops within the slot, then the bars can move radially if the induced forces exceed the restraining frictional forces in the slot. Under most circumstances, the frictional forces provided by the compression of the side ripple springs are sufficient to restrain the stator bars from moving even if radial clearance develops. However, should significant oil be introduced into the generator, the frictional forces provided by the side ripple springs will be reduced and, as a result, the radial forces induced during operation may be sufficient to cause the bars to vibrate. The combination of stator bar forces, radial clearance, and oil contamination can result in stator bar abrasion on any liquid-cooled stator winding regardless of the manufacturer of the generator.

It is important to recognize that stator bar abrasion can be prevented, even in the presence of significant oil contamination, by maintaining a radially tight stator winding. Stator slot support systems and windings undergo a gradual, long-term aging process. The rate at which loosening of the winding develops will be influenced by a complex combination of duty, oil ingress, and stator winding maintenance. This can be further complicated by the fact that rates of oil ingress can change during the life of the generator.

Generators with liquid cooled stator windings have higher bar forces than those with conventionally cooled windings and, therefore, may be more susceptible to bar vibration and wear since the higher forces will more readily overcome reduced frictional forces when oil contamination is present. Conditions leading to stator bar abrasion can develop after long periods of service and are associated with aging machines. Once radial clearance develops, sufficient to allow bar vibration to occur, rapid acceleration of the abrasion mechanism can occur if mitigating steps are not taken. Severe deterioration of the stator winding can occur within an interval between generator maintenance outages.

New GE generators are shipped with a tight stator wedging system and zero radial clearance in the stator slot. Long-term reliable operation of the stator winding is dependent upon the maintenance of a radially tight wedging system. The development of radial clearance in the stator slot is a service-, duty-, and maintenance-dependent condition. In the presence of oil contamination, radial clearance can lead to accelerated bar abrasion.

On the existing generator fleet, liquid-cooled stator bar abrasion is not expected to occur within the first 5 years of operation and may not occur at all within the lifetime of the generator. It can begin to develop within 5-10 years but evidence of the condition can still be difficult to observe. Stator winding insulation abrasion due to stator bar vibration appears to accelerate with time in the presence of oil contamination. Stator bar abrasion can be prevented if a radially tight (zero radial clearance) winding is maintained. It is vitally important to stop any abrasion which may be developing or presently occurring as soon as possible.

Design and process changes on new unit stator windings and existing unit stator rewinds are expected to improve the durability of the stator winding slot support system and to minimize future stator winding maintenance. These improvements will also allow for extension of generator maintenance intervals.

Adhering to a comprehensive and proactive inspection, testing, and maintenance program can minimize the risk of stator bar abrasion, and prolong the life of the generator stator winding.

The following information should be considered when planning inspections and testing for bar abrasion:

1.Age of the unit

2.Operational history-load cycling, start-stops, etc.

3.Inspection history - prior evidence of stator bar greasing and oil contamination

4.Generator maintenance history, particularly with respect to stator rewedging

5.Present rate of oil drainage from liquid level detector

6.Desired level of reliability

7.Risk tolerance

8.Planned maintenance outages

RECOMMENDATIONS

GE recommends performing the following tests and inspections at the first major generator maintenance outage following the first-year inspection if the generator is less than 5 years old. If the generator is more than 5 years old and the unit has a history of stator bar greasing or oil contamination, and the stator winding has never been rewedged, GE recommends performing the following tests and inspections at the earliest opportunity. In all other cases, the tests and inspections should be performed at the next major generator maintenance outage. It should be recognized that these tests and inspections can be performed utilizing GE's insitu inspection capabilities with the field in place.

GE strongly recommends, in all cases, that owners contact their local GE representative for additional information and for outage planning assistance.

Inspections and Tests

1) Visual Inspection

The generator stator should be inspected by a trained expert who is familiar with the design and construction of the stator winding. Evidence of oil contamination, radial clearance, greasing and other indications of stator bar movement within the stator slots should be noted. This can be accomplished visually with the field removed or with GE's MAGIC (Miniature Air Gap Inspection Crawler) insitu inspection system with the field in place. GE recommends that side ripple springs not be removed to expose wear surfaces since there is a risk of damaging the stator bar insulation during removal or reassembly of the springs. Recommendations for maintenance will be based, in part, on the results of this inspection.

2) Wedge Tightness Inspection

A stator wedge tightness inspection should be performed to determine the tightness profile of the wedges. This can be done using GE's MAGIC wedge tap system with the field in place or using traditional methods with the field removed. The results of this inspection will help determine the extent of rewedging, if any, needed to retighten the stator winding.

3) Clearance Testing

Wedge tightness may not necessarily indicate radial clearance at the ends of the slots and, therefore, special testing should be performed to determine if clearance exists. This is particularly important if oil contamination is present on the stator winding. Special testing techniques have been developed to determine the magnitude of radial clearance that may be present at the ends of the slots. This inspection can be performed with the field in place using the GE MAGIC insitu inspection system or with the field removed. Recommendations for maintenance will be based, in part, on the results of this test.

4) Electrical Testing

Prior to clearance testing and also prior to returning the generator to service, the stator winding should receive a high-potential test equal to 1.5 times rated line-to-line AC terminal voltage. This is consistent with the standard GE suitability-for-service testing recommendation described in TIL 1154-3 "Generator Test and Inspection".

Maintenance

1) Stator Bar Replacement

A severe degree of stator bar abrasion may result in a suitability-for-service high potential test failure and, consequently, the need to perform one or more stator bar replacements. Depending on the results of the high-potential testing, the repair may consist of a single top bar replacement, a partial rewind involving one or more bottom bars along with the necessary top bars, or a complete stator rewind. If there is evidence of stator bar abrasion and the stator winding passes a suitability-for-service high-potential test or a test is not performed, then the risks associated with continued operation should be evaluated on a case-by-case basis. GE is uniquely prepared to provide assistance with this evaluation.

2) Stator Rewedging

A recommendation to perform stator rewedging, if necessary, will be based on the results of the visual inspection, wedge tightness mapping, and clearance testing. In most cases, if evidence of stator bar abrasion is observed, a certain degree of rewedging will likely be recommended. Certain magnitudes of radial clearance, with or without evidence of stator bar abrasion, will also indicate a need to rewedge to minimize susceptibility to abrasion. It may be possible to postpone rewedging under certain conditions.

An improved stator wedging system is available which assures that stator bars remain forced to the bottom of the stator slot during long-term periods of service. This slot support system is expected to provide greater long-term stator winding durability, reduce susceptibility to the effects of stator winding oil contamination, minimize future stator winding maintenance, and allow for generator maintenance interval extension.

3) Oil Elimination/Prevention
Since oil can accelerate abrasion on stator bars, all attempts should be made to remove oil contamination and grease, if present, from the stator prior to returning the stator to service. It is essential that precautions are taken to prevent the introduction of additional oil into the stator in the future. The steps required to modify the endshields and provide a more robust sealing system are outlined in the recommendations of TIL 1098-3R2 entitled "Inspection of Generators with Water Cooled Stator Windings." It may also be possible to add additional bolting locations to the endshields to provide a tighter horizontal joint.

Contact GE for Assistance

Based on its test and inspection experience and OEM knowledge of the stator design and construction, GE is uniquely qualified to provide assistance in planning and performing appropriate tests and inspections for liquid cooled stator bar abrasion, interpret the results, and determine a prudent, cost-effective course of action. Due to the fact that information on liquid cooled stator bar abrasion is still evolving, owners are strongly encouraged to contact GE to review the status of their generator stator winding, obtain outage planning assistance, and obtain the latest information on this issue.

TIL-965: COPPER PARTICLE (COPPER DUST) CONTAMINATION OF GENERATOR FIELDS

PURPOSE

The purpose of this TIL is to make recommendations concerning internally generated copper particle (copper dust) contamination of generator fields. Accumulation of copper particles in the windings can cause field grounds and result in forced outages. These recommendations apply to all generators with multiple copper layers per turn of field conductor.

DISCUSSION

Generator fields designed with direct conductor cooling have field coils consisting of multiple layers of copper conductors in each turn. While there is insulation between the turns, there is none between the layers of each turn. For manufacturing and operational reasons, the coil build up in the slots is designed with moderate radial and transverse clearances.

When the unit is on turning gear, the coils are relaxed in the slots and the layers within a turn may move in a transverse direction relative to each other. See figure 1. At full speed, the coils are locked into position by centrifugal force and no relative transverse motion takes place. The rubbing caused by this relative movement for an extended period of time produces copper particles in the slots. In simulated tests in our laboratory, copper particles similar to those collected from some of the affected generator fields have been produced by this action.

These copper particles often gradually migrate towards the top of the coil slots due to the centrifuging action when the field is at operating speed. If a sufficient quantity of these copper particles accumulates in the side clearances between the creepage block and the slot armor, a field ground can result.

The copper particles may also accumulate across the insulation between turns and cause shorted field turns. The leakage current at such shorts over a long period of time can cause sufficient localized heating as to burn through the slot armor and create a field ground.

Twenty instances (thirteen 2-pole units and seven 4-pole) of copper particle contamination of generator fields have been reported since they were first observed in 1971. Of these, nine were forced outages due to a field ground attributed to copper particle accumulation. Five 2-pole and four 4-pole units were involved. All of these units have been known to have had extensive operation on turning gear either before startup or due to plant generation schedules.

Extended operation on turning gear is the most significant contributor to the generation and accumulation of copper particles. The amount of cumulative turning gear operation that will cause a field ground cannot be predicted, as there are many variables involved. It is not possible to identify potential problems due to copper particle accumulation by visual inspection of the field externally. Only after removing at least one retaining ring and several slots of wedges and creepage blocks have we been able to see copper particle accumulation. In some cases it may be necessary to lift some field coil turns before copper particle accumulation can be seen.

Although some copper particles may be present in many fields with this construction, it does not, however, necessarily mean that a field ground is imminent.

RECOMMENDATIONS

1. Minimize turning gear operation consistent with turbine operating instructions. This will reduce copper particle generation, thus minimizing the probability of field winding problems due to copper particle accumulation.

2. On fields that are known to have been on turning gear for extended periods of time, during the next planned maintenance outage, disassemble at least one retaining ring, remove coil slot wedges and creepage blocks from all coil slots and vacuum clean the coils thoroughly. It is not possible to remove all copper particles by vacuuming, but this action will delay the migration of copper particles to the tops of the slots and a consequent field ground. Several fields which experienced field grounds have been cleaned in this manner and returned to service with no recurring field ground for over seven years.

3. In those cases where time or other factors do not permit a complete rewind to be accomplished, synthetic rubber "O" ring gaskets can be installed on the sides of the creepage blocks, as shown in figure 2. This is expected to significantly reduce the accumulation of copper particles across the full thickness of the creepage block and, thus, delay the occurrence of a field ground by contamination near the top of the slot. All field grounds caused by copper particles experienced so far, with the exception of one, could have been delayed or possibly prevented by this modification.

To make this modification, sufficient outage time must be available to remove all creepage blocks and machine grooves on the sides to accommodate the gaskets. If outage time is critical, a complete set of creepage blocks with the grooves machined can be ordered in advance from the factory. Some fields have creepage blocks that cannot be modified to accept the synthetic rubber gasket. On these fields a complete set of new creepage blocks will be required.

Laboratory tests on a simulated service model indicate that the gaskets appear to be effective in controlling the particle migration, and this modification has been applied to two 4-pole fields to gain actual in-service experience. Since they have not yet been disassembled for inspection, the long-term effectiveness of this modification remains to be proven in service.

4. In order to completely PREVENT the generation of copper particles while the unit is on turning gear, the most reliable and permanent modification is to completely rewind the field, using the existing

copper, but replacing all slot and turn insulation. During this rewind, insulating glass-reinforced layer separators will be added between layers of each turn, thus preventing the rubbing between the layers of copper. The rewind also provides an opportunity to clean out all copper particles previously accumulated. Figure 3 shows the use of layer separators. Most fields have enough radial clearance to allow the addition of layer separators. However, in a few rare cases, some additional modifications may be called for.

Your GE Apparatus and Engineering Service representatives can assist you in planning the outage to accomplish the above recommended inspection and modification. They can schedule the necessary skilled labor and technical direction and order parts in advance to ensure smooth progress of work during the outage.

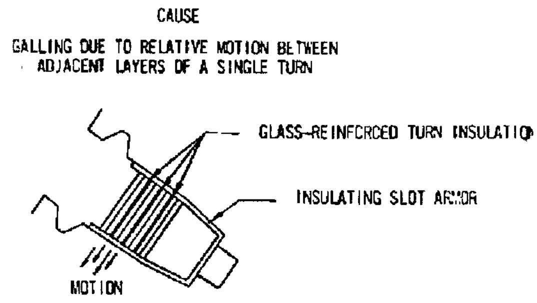


FIGURE 1

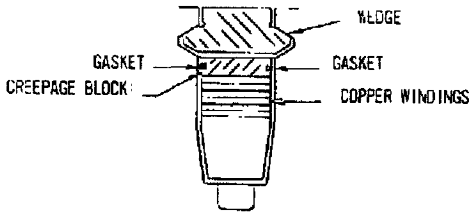


FIGURE 2

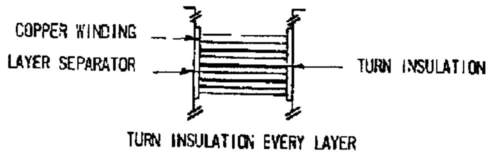


FIGURE 3

Customer:	Intermountain Power Project	**Generator DL**	280T150
ICN No.	G4578201	**Turbine No.**	270T150
Generator No.	280T150	**Frame Size**	112 – 54.3 x 280
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